

NASA
7N-45-TM
130479
P.10

Journal of the Mississippi Academy of Sciences

Volume XXXIII, 1988

8. Aquatic Plants For pH Adjustment and Removal Of Toxic Chemicals and Dissolved Minerals From Water Supplies

B. C. WOLVERTON, PH.D.
Senior Research Scientist
National Aeronautics and Space Administration
John C. Stennis Space Center
Stennis Space Center, MS 39529-6000

BYRON KEITH BOUNDS
Chemist
Sverdrup Technology, Inc.
John C. Stennis Space Center
Stennis Space Center, MS 39529-6000

N93-70418

Unclass

29/45 0130479

Abstract. Microbial plant filter systems with torpedo grass (*Panicum repens*) and Southern bulrush (*Scirpus californicus*) were evaluated for their utility in adjusting pH levels and removing potassium ferric cyanide, potassium cyanide, pentachlorophenol (PCP) and dissolved minerals from contaminated water. The initial concentrations of cyanides were in the range of 0.72-32.8 ppm and all were reduced to <0.2 ppm in 24 hrs with bulrush. The initial average PCP concentration of 0.85 ppm was reduced to an average of 0.04 ppm in 24 hrs with torpedo grass.

The total dissolved solids (TDS) in the torpedo grass filter system were reduced from 988 mg/L to 588 mg/L in 7 days with a 40% water loss due to evapotranspiration. Adjustment for the water loss represents a TDS removal rate of approximately 83%.

Plant/rock filters also demonstrated the ability to adjust pH levels from 5 to near 7 in several hours.

Introduction. The rapid growth over the past few years of using aquatic plants for treating various types of wastewater is evidenced by the many publications in this area (4,5,9,10,12-17,21-45). The National Aeronautics and Space Administration (NASA), at the John C. Stennis Space Center (SSC) in South Mississippi, has been conducting research in the field of vascular plant use for space and earthly applications for over 15 years. The initial efforts involved aquatic plants in lagoons and microbial filters for treating and recycling domestic wastewater and toxic heavy metal removal. These authors have observed that several vascular aquatic plant species are very versatile and are

(NASA-TM-108059) AQUATIC PLANTS
FOR pH ADJUSTMENT AND REMOVAL OF
TOXIC CHEMICALS AND DISSOLVED
MINERALS FROM WATER SUPPLIES, 8
(NASA) 10 P

capable of improving water quality in many ways. A series of experiments, using rock filters that supported the growth of two aquatic macrophytes, torpedo grass (*Panicum repens*) and Southern bulrush (*Scirpus californicus*), were conducted to remove toxic organics and inorganics, reduce dissolved solids in the form of mineral salts, and buffer pH extremes back to neutral conditions.

Pentachlorophenol is a highly toxic phenolic derivative that is widespread in its distribution mainly due to its use in wood preservatives and pesticides. It is structurally persistent and is considered potentially carcinogenic when ingested, inhaled or absorbed through the skin. It has been listed by the U. S. Environmental Protection Agency (EPA) as a priority pollutant for screening, and is the subject of other degradation studies (6,7,11).

Likewise, cyanide and its derivatives are listed as regulated inorganic pollutants by the US EPA with a maximum allowable quantity of 0.025 mg/L in drinking water according to 1985 amendments of the Safe Drinking Water Act of 1974 (18). It is primarily used in the photography industry, in the extraction process of precious metals and as a precursor in the manufacture of plastics.

Another parameter of growing concern in our water supplies is dissolved solids. When the total dissolved solid levels in water are greater than 500mg/L, the water is considered undesirable as a source of drinking water and irrigation problems are created for farmers growing certain crops. Each year, more agricultural land is lost from production as a result of saline conditions caused by irrigation. To date, approximately one-tenth of the world's 210 million ha (519 million ac) of irrigated land has deteriorated because of salinization (2). Approximately six million ha (15 million ac) of moderately saline soil are found in North America. Another type of salinity problem occurring in regions such as the Mississippi Gulf Coast is created by intrusion of salt water from the Gulf into the ground water used for both drinking and irrigation purposes.

Currently the most prominent method of removing salt and other dissolved solids from water supplies today is reverse osmosis. Reverse osmosis requires that the influent water be pumped, usually under high pressure, through special membrane filters in order to cause the migration of dissolved substances in a direction against the natural osmotic pressure. This process is very costly, energy intensive, and has various other problems, one of which is the biological fouling of the membrane that decreases the flow rates and in turn increases the pressure required to achieve the desired water flow. As a result of the fouling problem frequent, time consuming, and costly membrane cleaning must be done.

To date, biological methods of salt removal using halophytes or salt-concentrating plants have received little attention. However, the ability of certain plants, both aquatic and terrestrial, to concentrate salt is widely recognized (1,3,20).

Increased interest in pH adjustment of water supplies has developed because of the concern generated in acid rainfall studies. Research has shown that with increased nitrogen oxide emissions from motor vehicles and sulfur dioxide emissions from coal-burning plants, a reduction in the pH of rainfall and other forms of precipitation is detected. Reduced pH in water supplies directly af-

fects drinking water sources, irrigation supplies, wildlife and man-made objects.

A promising, alternative to reverse osmosis and other physical treatment processes for water quality improvement was demonstrated in this study. The sequential supporting experiments are outlined below.

Description of Experimental Systems. Two galvanized steel troughs (50.5 cm W x 30.5 cm D x 298 cm L), filled with rocks (2.5 - 7.5 cm in diameter) were used as microbial filters. These filters were approximately three years old and were well conditioned with an active biofilm developed in previous domestic wastewater experiments.

One trough was planted with torpedo grass (*Panicum repens*) approximately 5 months prior to experimentation. The second trough was planted with Southern bulrush (*Scirpus californicus*) approximately 3 months prior to experimentation. Both plant species were well-rooted in their respective filters.

Procedure and Analyses. In the first phase of study, pentachlorophenol (PCP) in a methanol concentrate was mixed with freshly collected domestic wastewater from one of the SSC lagoons in a polyethylene plastic container that served as a chemical reservoir during testing. The PCP-spiked wastewater was pumped into the rock filters using Cole-Parmer Series 7141 metering pumps. The pumping rate was controlled to allow a 24 hour retention time in rock filters. Routine analyses were done on the samples to test for pH, dissolved oxygen (DO), temperature, five-day biochemical oxygen demand (BOD₅) and total organic carbon (TOC). All analyses followed procedures outlined in Standard Methods (19).

Samples for PCP were collected in glass containers and extracted immediately following collection. The acid extraction of PCP was performed according to Longbottom and Lichtenberg (8) and the concentration was determined in a Hewlett Packard Model 5880A gas chromatograph equipped with a flame ionization detector (FID) and a HP 25 m-Ultra Performance cross-linked 5% phenyl methyl silicone capillary column.

In the second phase of study, two cyanide compounds, potassium cyanide and potassium ferric cyanide, were used individually in place of the pentachlorophenol for 4 and 2 week experimental durations, respectively. Two different cyanide compounds were studied to determine if the plant systems would demonstrate a selective preference. Cyanide concentrations in influent and effluent samples were measured using an Orion 901 Ionalyzer equipped with a Model 94-06 cyanide ion electrode. The routine analyses previously described were also performed on the samples.

In the third phase of study, the same two plant/rock filters were used in a batch study of salt uptake by the plants. Eight compounds, calcium chloride, sodium chloride, magnesium chloride, potassium chloride, calcium sulfate, sodium sulfate, magnesium sulfate and potassium sulfate were collectively mixed in 76L (20 gal) of water to achieve a 0.01 M concentration of each salt and introduced into each of the rock filter troughs. An influent sample of the salt solution was taken prior to addition to the rock filter and effluent samples were col-

lected on a daily basis from the opposite end of the troughs. The rock filters were drained and the salt solution was changed on a regular basis either at a 7 or 14 day interval. Testing was done daily for pH and TDS. Water levels in the troughs were measured daily and recorded to calculate water loss due to plant uptake and evapotranspiration.

In the final phase of experimentation, the additional salt was not added and the pH of influent water was reduced to approximately 5.0 using concentrated H_2SO_4 . The testing was maintained in a batch method and samples were collected hourly for the first three hours and then daily for a seven day period. Influent samples were collected prior to entering the rock filters and effluent samples were collected at the opposite end of the filters. pH readings were taken using a Fisher Accumant^R pH meter.

Results. Average data from 33 pentachlorophenol (PCP) experiments using the rock filter with torpedo grass during a nine week period is shown in Table 1. The initial PCP concentrations ranged from 0.17 to 5.7 mg/L and the removal rates for a 24 hour retention time ranged from 76.6% to 99.4% with an average of 95.5%.

Table 1. Pentachlorophenol data for torpedo grass/rock filter.*

	Average Concentrations	
	Influent	Effluent
pH	6.88 \pm 0.36	6.90 \pm 0.20**
DO, mg/L	3.3 \pm 1.3	4.1 \pm 1.1
Temp, °C	24.0 \pm 4.8	24.5 \pm 1.6
BOD ₅ , mg/L	115.5 \pm 46.5	22.5 \pm 11.2
TOC, mg/L	65.5 \pm 19.0	28.3 \pm 5.9
Pentachlorophenol (PCP), mg/L	0.85 \pm 1.2	0.4 \pm 0.03

*Average data from 33 experiments

**Standard deviation

The efficiency of a Southern bulrush aquatic plant marsh filter to remove potassium cyanide and potassium ferric cyanide from water contaminated with these chemicals is shown in Table 2. The initial potassium cyanide concentrations range from 0.2 to 6.35 ppm while the levels of potassium ferric cyanide range from 3.5 to 32.8 ppm. Within a 24 hr period all cyanide levels were reduced to below detection levels of 0.2 ppm. No difference was seen in the torpedo grass/rock filter's effect on the two different cyanide compounds.

In both the pentachlorophenol and cyanide studies, the plant/rock filters were very effective in improving the water quality according to the routine analyses that are also listed in Tables 1 and 2. Based on the averages of the col-

Table 2. Cyanide data for southern bulrush/rock filter.

	Average concentrations	
	Influent	Effluent
pH	7.08 \pm 0.38	7.06 \pm 0.21**
DO, mg/L	3.7 \pm 1.0	4.2 \pm 1.0
Temp, C	26.1 \pm 1.5	25.4 \pm 1.0
BOD ₅ , mg/L	85.8 \pm 43.3	16.8 \pm 10.8
TOC, mg/L	65.0 \pm 22.1	21.6 \pm 5.8
Potassium	3.0 \pm 1.8	<0.2 \pm 0.0
cyanide, mg/L*		
Potassium	12.6 \pm 10.3	<0.2 \pm 0.0
ferric cyanide, mg/L***		

*Average data from 14 experiments

**Standard deviation

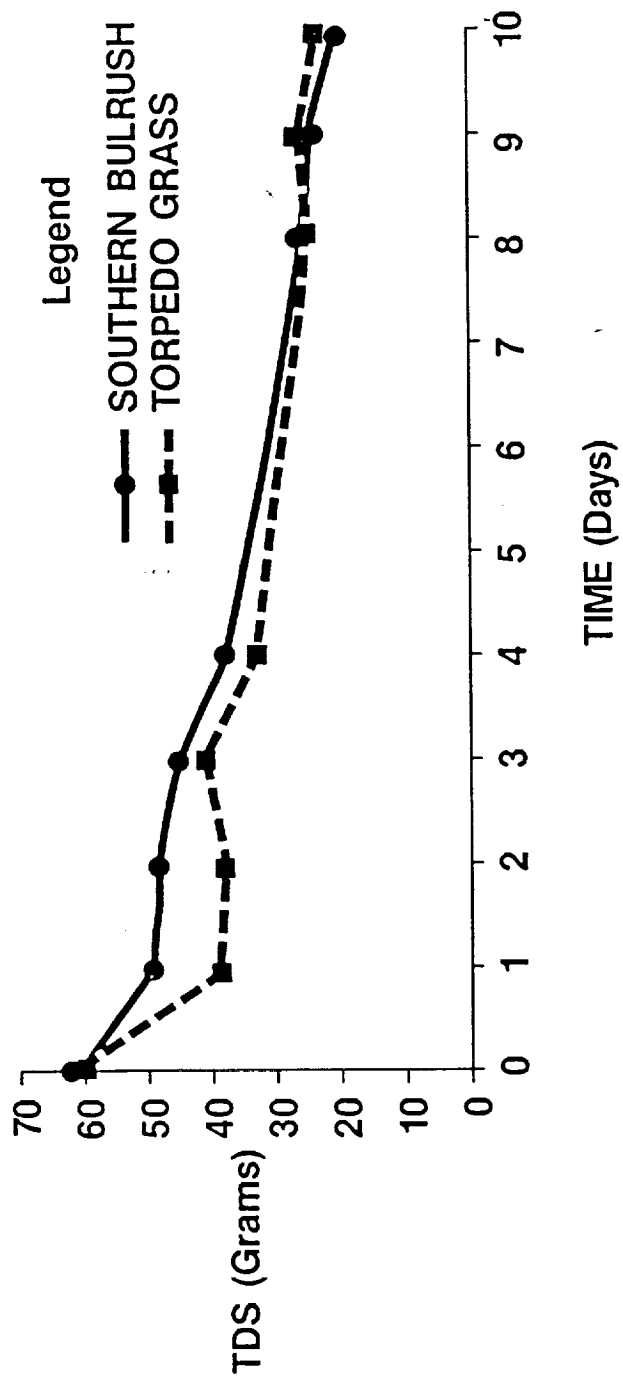
***Average data from 8 experiments

lective data of each study, the pH readings of influent samples were buffered to a more neutral pH of 7 and dissolved oxygen levels were increased on an average of 0.5 mg/L for the bulrush/rock filter and 0.8 mg/L for the torpedo grass/rock filter. In both filters the average BOD₅ and TOC were reduced significantly.

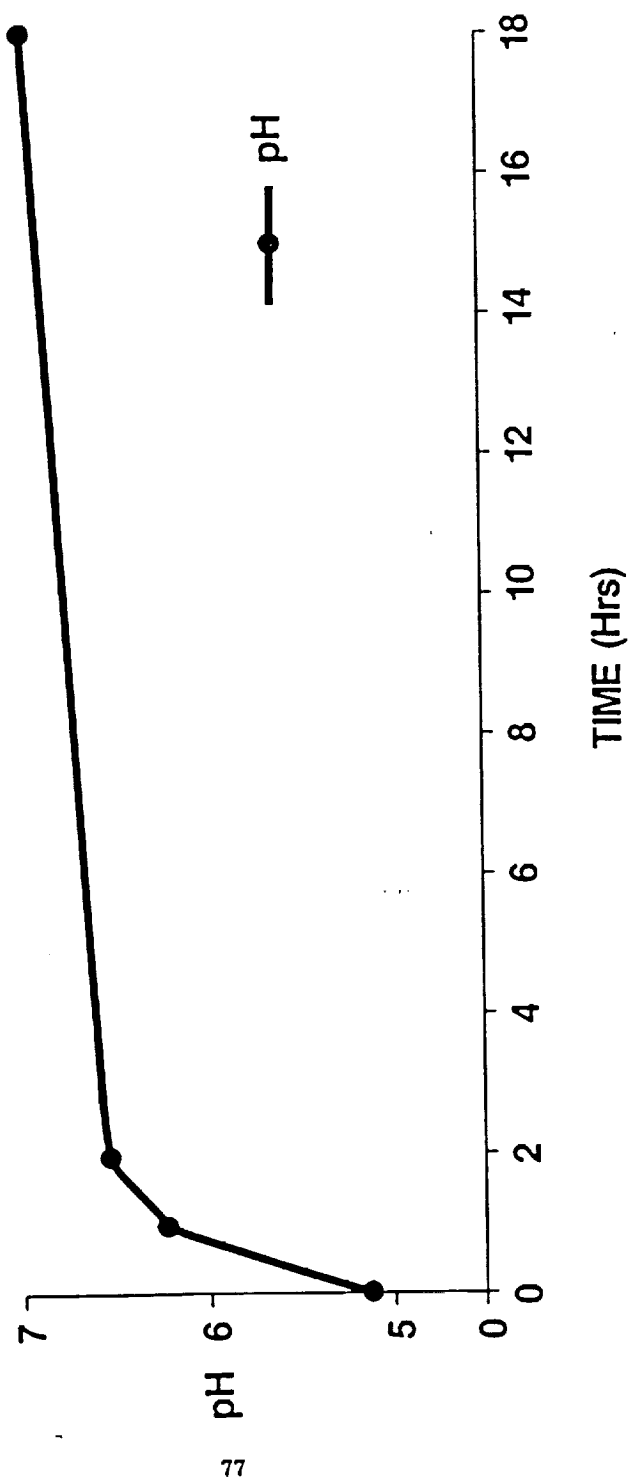
The ability of Southern bulrush and torpedo grass marsh filters to remove total dissolved solids (TDS) in the form of calcium, potassium, sodium and magnesium chlorides and sulfates is shown in Figure 1. These two aquatic plants were similar in their ability to remove dissolved minerals from water. Greenhouse studies demonstrated the potential of salt-tolerant plants such as torpedo grass and Southern bulrush for removing dissolved minerals from water. For each 1.5 m² of plant/filter surface area, approximately 2.5 g of dissolved minerals can be removed during the first week. In studies extended beyond the first week, a continual removal of the dissolved minerals did gradually occur until the plants reached a near saturation level. Therefore, it can be concluded that frequent plant harvesting will increase the mineral removal rates. Greenhouse observations suggest that 8-9 week harvest intervals should be maintained during the growing season. It can also be noted from data not shown that pH levels in both plant/rock filters were reduced from an average pH of 8.1 of influent samples to 6.5 of effluent samples within 24 hrs.

Bulrush marsh filters have also demonstrated the ability to adjust pH levels from 5 to near 7 within 24 hrs as seen in Figure 2. This effect can also be seen in the pH results of the torpedo grass marsh filter, indicating that both plants have the ability to tolerate acidic pH conditions. In both filters, the buffered pH of approximately 7.0 was maintained throughout the 7 days of testing.

**FIGURE 1. ARTIFICIAL MARSH WASTEWATER TREATMENT SYSTEM
COMBINED PLANT/ROCK FILTERS TO REMOVE DISSOLVED
MINERALS FROM WATER.**



**FIGURE 2. ARTIFICIAL MARSH SYSTEMS USING SOUTHERN BULRUSH
FOR ADJUSTING THE pH LEVEL IN ACIDIC WATERS.**



LITERATURE CITED

1. Briens, M. and F. Larher. 1982. Osmoregulation in halophytic higher plants: A comparative study of soluble carbohydrates, polyols, betaines and free proline. *Plant Cell Environ.* 5:257.
2. Brown, L. R. 1981. World population growth, soil erosion, and food security. *Science*, 214:1002-721.
3. Collander, R. 1941. Selective absorption of cations by higher plants. *Plant Physiol.* 16:691-721.
4. Culley, D. D., Jr., and A. E. Epps. 1973. Use of duckweed for waste treatment and animal feed. *J. Water Poll. Control Fed.*, 45:337-347.
5. Dinges, Ray. 1982. *Natural Systems for Water Pollution Control*. Published by Van Nostrand Reinhold Co., New York, NY. pp. 252.
6. Government Institutes, Inc. 1985. Environmental Statutes. Government Institutes, Inc., Rockville, MD. p. 366.
7. Hickman, G. T. and J. T. Novak. 1984. Acclimation of activated sludge to pentachlorophenol. *J. Water Poll. Control Fed.* pp 56, 364.
8. Longbottom, J. E. and J. J. Lichtenberg (Eds.). 1982. Methods for organic chemical analysis of municipal and industrial wastewater. U. S. EPA Document No. EPA-600/4-82-057. Environmental Monitoring and Support Laboratory, Cincinnati, OH. Method 625.
9. McDonald, R. C. 1981. Vascular plants for decontaminating radioactive water and soils. NASA Tech. Memorandum, TM-X-72740., NTSL, MS.
10. McDonald, R. C. and B. C. Wolverton. 1980. Comparative study of wastewater lagoon with and without water hyacinth. *Econ. Bot.*, 34(2):101-110.
11. McCaleb, R. C. and B. K. Bounds. 1987. Biological Activated Carbon. In: Proceedings of American Water Works Association Research Foundation, Water Reuse Symposium IV, August 2-7, 1987. Denver, CO.
12. Reddy, K. R. 1983. Fate of nitrogen and phosphorus in a wastewater retention reservoir containing aquatic macrophytes. *J. Environ. Qual.*, 12:137-141.
13. Reddy, K. R. and W. F. DeBusk. 1984. Growth characteristics of aquatic macrophytes cultured in nutrient-enriched water: I. Water hyacinth, water lettuce, and pennywort. *Econ. Bot.*, 38:225-235.
14. Reddy, K. R. and W. F. DeBusk. 1985. Nutrient removal potential of selected aquatic macrophytes. *J. Environ. Qual.*, 14:459-495.
15. Reddy, K. R., D. L. Sutton, and G. E. Bowes. 1983. Biomass production of freshwater aquatic plants in Florida. *Proc. Soil Crop Sci. Soc.*, 42:28-40.
16. Rittman, B. E. and P. L. McCarty. 1980. Model of steady-state biofilm kinetics. *Biotech. and Bioeng.*, 22:2343-2357.
17. Rusoff, L. L. and B. C. Wolverton. 1978. Vascular aquatic plants - a source of foodstuff for animals and man. I. Water Hyacinth. Presented at the XI International Congress of Nutrition, Rio de Janeiro, Brazil.
18. Safe Drinking Water Act. Amended 1985. Public Law 93-523, 93rd Congress, Section 433.
19. Standard Methods for the Examination of Water and Wastewater, 16th Ed. 1985. American Public Health Association, Washington, DC.
20. Thompson, W. W. 1975. Salt glands. In: A Poljakoff-Mayber and J. Gale (Eds.), Plants in saline environments. Springer-Verlag, Berlin.
21. Wolverton, B. C. 1979. Water hyacinth. *Mazingira* (United Kingdom) 11:59-65.
22. Wolverton, B. C. 1979. Engineering design data for vascular aquatic plant wastewater treatment systems. Aquaculture systems for wastewater treatment. EPA 430/9-80-006. 179-192.
23. Wolverton, B. C. 1980. Water hyacinths for controlling water pollution. *Water Pollution and Management Review Jawaharlal Neru University*, New Delhi, India. pp. 9.
24. Wolverton, B. C. 1982. Hybrid wastewater treatment system using anaerobic microorganisms and reed (*Phragmites communis*). *Econ. Bot.*, 36 (4):373-380.

25. Wolverton, B. C. and R. C. McDonald. 1976. Water hyacinths, (*Eichhornia crassipes*) (Mart.) Solms, a renewable source of energy. Proceedings of A Conference on Capturing the Sun Through Bio-conversion, coordinated by Washington Center for Metropolitan Studies, Washington, DC 240-252.
26. Wolverton, B. C. and R. C. McDonald. 1976. Water hyacinths: a natural biological filtration system. Proceedings of the Association for Rational Environmental Alternatives, Wellsboro, PA.
27. Wolverton, B. C. and R. C. McDonald. 1977. Wastewater treatment utilizing water hyacinths (*Eichhornia crassipes*) (Mart.) Solms. In: Treatment and Disposal of Industrial Wastewaters and Residues. Proceeding of the National Conference on Treatment and Disposal of Industrial Wastewaters and Residues, Houston, TX. 205-208.
28. Wolverton, B. C. and R. C. McDonald. 1978. Water hyacinths productivity and harvesting studies. *Econ. Bot.*, 33(1):1-10.
29. Wolverton, B. C. and R. C. McDonald. 1978. Nutritional composition of water hyacinths grown on domestic sewage. *Econ. Botany*, 32(4):363-370.
30. Wolverton, B. C. and R. C. McDonald. 1979. Bio-accumulation and detection of trace levels of cadmium in aquatic systems using *Eichhornia crassipes*. Presented at the National Institute of Environmental Health Sciences Workshop on Higher Plant Systems as Monitors of Environmental Mutagens, Orlando, FL. *Env. Health Persp.*, U. S. Department of HEW 27:161-164.
31. Wolverton, B. C. and R. C. McDonald. 1979. The water hyacinth from prolific pest to potential provider. *AMBIO*, 8(1):2-9.
32. Wolverton, B. C. and R. C. McDonald. 1979. Upgrading facultative wastewater lagoons with vascular aquatic plants. *J. Water Poll. Cont. Fed.*, 51(2):305-313.
33. Wolverton, B. C. and M. M. McKnown. 1976. Water hyacinths for removal of phenols from polluted waters. *Aquatic Bot.* 2:191-201.
34. Wolverton, B. C. and R. C. McDonald. 1980. Vascular plants for water pollution control and renewable sources of energy. Proceedings Bio-Energy '80, Atlanta, GA, pp. 120-122.
35. Wolverton, B. C. and R. C. McDonald. 1981. Energy from vascular plant wastewater treatment systems. *Econ. Bot.*, 35(2):224-232.
36. Wolverton, B. C. and R. C. McDonald. 1981. Natural processes for treatment of organic chemical waste. *The Environ. Prof.*, 3:99-104.
37. Wolverton, B. C. and R. C. McDonald-McCaleb. 1986. Biotransformation of priority pollutants using biofilms and vascular plants. Submitted for publication in *J. Miss. Acad. of Sci.*
38. Wolverton, B. C., R. M. Barlow and R. C. McDonald. 1976. Application of vascular aquatic plants for pollution removal, energy, and food production in a biological system. *Bio. Cont. of Water Poll.*, University of Pennsylvania, Press, Philadelphia, PA 141-149.
39. Wolverton, B. C., R. C. McDonald, and W. R. Duffer. 1983. Microorganisms and higher plants for wastewater treatment. *J. Environ. Qual.*, 12(2):236-242.
40. Wolverton, B. C., R. C. McDonald, and L. K. Marble. 1984. Removal of benzene and its derivatives from polluted water using the reed/microbial filter technique. *J. Miss. Acad. of Sci.*, 29:119-127.
41. Wolverton, B. C., C. C. Myrick, and K. M. Johnson. 1984. Upgrading septic tanks using microbial/plant filters. *J. of Miss. Acad. of Sci.*, 29:19-25.
42. Wolverton, B. C. and R. C. McCaleb. 1987. Pennywort and duckweed marsh system for upgrading wastewater effluent from a mechanical package plant. In: K. R. Reddy and W. H. Smith (Eds.), *Aquatic plants for wastewater treatment and resource recovery*. Magnolia Publishing Inc., Orlando, FL. pp. 289-294.
43. Wolverton, B. C. 1987. Artificial marshes for wastewater treatment. In: K. R. Reddy and W. H. Smith (Eds.), *Aquatic plants for wastewater treatment and resource recovery*. Magnolia Publishing Inc., Orlando, FL. pp. 141-152.
44. Wolverton, B. C. 1987. Natural systems for wastewater treatment and water reuse for space and earthly applications. In: Proceedings of American Water Works Association Research Foundation, Water Reuse Symposium IV, August 2-7, 1987, Denver, CO.

45. Wolverton, B. C. 1987. Aquatic plants for wastewater treatment: an overview. In: K. R. Reddy and W. H. Smith (Eds.), Aquatic plants for wastewater treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. pp. 3-15.